

APPLICATION OF THE CIREN METHODOLOGY TO THE STUDY OF PEDESTRIAN CRASH INJURIES

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ABSTRACT

The Crash Injury Research Engineering Network, CIREN, was initiated by NHTSA as a collaborative forum for detailed investigation of motor vehicle crashes. This arrangement brings together experts from medicine, academia, industry, and government to perform detailed analyses of the injuries sustained in specific collision modes. The CIREN program has typically focused on vehicle occupants, but in 2002 the Honda Inova Fairfax Hospital CIREN Center established a special program for pedestrian crash investigations. The goal of the center has been to – complete detailed crash investigations for impacts between a pedestrian and a passenger car or light truck. Detailed medical and anthropometric data are collected at the level one trauma center and expert investigations of the vehicle and crash scene are conducted. Multi-body simulation models are sometimes used to estimate impact kinematics for the pedestrian and to validate vehicle speed estimations and initial position of the pedestrian. An interdisciplinary team analyzes the data and develops a consensus for the most likely impact scenario and injury mechanisms. This paper presents our initial experience from investigating over twenty pedestrian collisions. We will discuss the challenges associated with collecting and analyzing this data as well as initial observation of injury trends and mechanisms encountered.

INTRODUCTION

Crash Injury Research & Engineering Network (CIREN)

To understand motor-vehicle crashes and mitigate the resulting fatalities and injuries, crash investigation and reconstructions have long played an important role. Government entities, safety researchers, automotive suppliers, and vehicle manufactures have put a significant effort into studying these crashes in order to understand the injuries that occur and the mechanisms involved.

In the 1990's, the US National Highway Traffic Safety Administration (NHTSA) identified a need to collaborate with medical personal, university researchers, and vehicle engineers in the detailed investigation of motor-vehicle crashes. From this vision, the CIREN program was established.

The CIREN program currently includes ten centers around the country that are based at hospitals with level 1 trauma centers. Funding for many of these centers is provided by NHTSA, but due to valuable information developed there are additional centers supported by industry.

The primary focus of the CIREN program is to investigate and analyze front, side, and rollover crashes. In some cases, the program has sought the collection of special cases to look at specific areas of highway safety that are of particular concern.

Honda Inova Fairfax Hospital CIREN Center

The Inova Regional Trauma Center (IRTC) is the only Level One Trauma Center in Northern Virginia. It is a component of Inova Fairfax Hospital, a 753-bed facility located in Fairfax County, Falls Church, Virginia. Fairfax County is a diverse urban county and the most populous jurisdiction in both Virginia and the Washington metropolitan area. In 1999, the IRTC became the 9th CIREN center and the only non-university based CIREN center in the United States. This center operates as collaboration between the IRTC, University of Virginia, Fairfax County emergency medical services, and Honda R&D.

CIREN centers typically study only passenger vehicle crashes. In 2002, Honda partnered with the IRTC center, and the study of pedestrian and motorcycle crashes was added as an area of special investigation. An average of 32,000 car crashes occurs in Fairfax County annually. The IRTC treats approximately 3,400 critically injured patients each year and 140 of these are pedestrian crashes. Pedestrian injuries in Fairfax County have the highest average hospital charges and longest hospital stays when compared to other motor vehicle caused injuries. This CIREN Center is currently the only Level One Trauma Center in the United States that studies pedestrian and motorcycle crashes.

Pedestrian Injury

Pedestrian crashes present a universal challenge for public health, trauma medicine, and traffic safety professionals in all motorized societies throughout the world. More than a third of the approximately 11.2 million people that are killed or injured in road traffic crashes every year are pedestrians (Crandall et al., 2002). Considering fatalities only, approximately 760,000 (65%) are pedestrians (World Bank, 2001). In the US alone, approximately 70,000 (2.4%) of the 2,889,000 who were injured and 4,749 (11.1%) of the 42,643 who were killed in road traffic crashes during the year of 2003 were pedestrians (NHTSA, 2005). The abovementioned statistics support Brainard et al. (1989), who stated that pedestrian casualties sustain more multi-system injuries with concomitant higher injury severity scores and mortality rates than vehicle occupants.

Automotive safety research has traditionally focused on developing knowledge, systems, and devices for protecting vehicle occupants. The lack of development and implementation of automotive countermeasures for pedestrian safety has stemmed primarily from a societal view that the injury caused by a large, rigid automobile striking a small, fragile pedestrian cannot be substantially reduced by altering

the vehicle structure. Automotive safety researchers are now exploring the theory that the same safety design principles that have resulted in substantial safety benefits for occupants might be extended to reduce the aggressiveness of motor vehicles to pedestrians. Based on these principles, several concepts of pedestrian safety countermeasures for minimizing the frequency and severity of injuries to the lower extremities (Aldman et al., 1985; Harris and Grew, 1985; Ishikawa et al., 1992, 1994; Nagatomi et al., 1996; Detweiler and Miller, 2001) and head (Okamoto et al., 1994; Fredriksson et al., 2001) have been proposed. A further step towards reducing the frequency and severity of injuries to pedestrian victims is the pedestrian test protocol included in the European New Car Assessment Programme (EuroNCAP). As part of a program to provide consumers and manufacturers with information on the impact performance of new cars sold in Europe, EuroNCAP evaluates the vehicle aggressiveness towards the pedestrian lower extremity and head by measuring the impact response of mechanical leg and head forms propelled into the vehicle front and hood structures.

CIREN Pedestrian Crash Investigations

As vehicle manufactures are working on the development of vehicle based systems to mitigate the extent and severity of pedestrian injuries, it has become evident that continued pedestrian crash investigations are necessary. These continued investigations are necessary for gaining a detailed understanding of pedestrian injuries and their injury mechanisms as well as for identifying the effects of changing vehicle fleets.

Application of the CIREN program methodology to pedestrian crash investigations presents a unique opportunity to gain a detailed understanding of injuries and injury mechanisms from a limited number of pedestrian crashes. These investigations provide information about impact kinematics, vehicle interactions and injury response trends.

METHODOLOGY

Case Selection

All pedestrian cases that arrive at IRTC are reviewed on a daily basis to identify those that meet the enrollment criteria for being part of the CIREN pedestrian crash investigation program. Each case must meet the following criteria to be eligible for enrollment:

- Hospital admission with AIS 2+ injury
- Pedestrian is struck by the front of the vehicle and is upright upon impact
- Striking vehicle is a passenger vehicle, SUV, minivan or small pick up truck

Screening, Enrollment & Consent

The medical record for each identified case is reviewed to determine injury and crash criteria. The study coordinator visits eligible patients and/or family members, explains the study, and requests consent. Potential study participants are required to sign an Informed Consent, a six-page document that explains the study, risks, benefits and patient rights. Patients are assured that their treatment will not be affected in any way whether they choose to participate or not. Once informed consent is obtained, the patient is interviewed, measurements are taken and photos of contusions, abrasions and lacerations are made. The crash reconstructionist is notified of the date and location of the crash. He contacts the proper jurisdiction's police department and attempts to obtain the crash report in an effort to identify the vehicle owner. The crash reconstructionist works with local police departments to obtain scene photos and additional crash information. He then visits the vehicle owner's residence in an effort to obtain Informed Consent. When consent is obtained, the vehicle can then be inspected.

Data Collection

Data collection for pedestrian cases collected at the CIREN center follows the guidelines of the National Highway Traffic Safety Administration's Pedestrian Crash Data Study (PCDS).

Medical Data

Medical information is collected from both the detailed hospital records and records of the pre-hospital care providers. The Fire and Rescue department that treated the pedestrian at the scene is notified, and pre-hospital information is obtained from their records. The full medical record is also reviewed in detail to obtain additional medical information. Injuries and procedures are assigned AIS, IDC-9 and CPT codes consistent with the patient's injuries and procedures. A research fellow and trauma surgeon review radiological records and select the best images to be included in the CIREN case file. Once all the medical data is collected, the data is entered into a database and the case can be prepared for Case Review. A social worker affiliated with the CIREN Center contacts the study participant

at 6 months and 12 months following the crash to obtain outcome data.

Vehicle & Crash Data

When a suitable case has been identified, the crash investigator attempts to obtain a copy of the police crash report. Information on the crash report provides information about date, time, and location of the crash, the vehicle involved, and identifies the owner and driver of the involved vehicle. Scene diagrams, photos, witness statements, and notes are also collected from this report.

In order to do a detailed inspection of the involved vehicle, the crash investigator attempts to make contact with the vehicle owner. If the vehicle owner agrees to the study, a signed consent form is completed. The involved vehicle is located, and the crash investigator conducts a detailed examination of the vehicle in accordance with the protocols employed by PCDS. The vehicle is documented by photographs, diagrams and video imaging; with special attention to damage at and under the surface of the vehicle. Photographs are sanitized, and data points obtained from the vehicle, crash scene and police crash reports are placed in the database.

The crash scene is also examined for physical evidence following the PCDS protocols. A scene diagram is prepared, and the crash investigator estimates an impact speed from the pedestrian throw distance and skid mark evidence.

Reconstruction & Simulation

Using a mathematical dynamic modeling software program, MADYMO (TNO, 2004), a selection of cases is reconstructed using the crash data. Each reconstruction selected is simulated using the following prioritization for matching criteria.

Vehicle Model Selection

There are three options for vehicle model selection. The optimal choice is a model already available within the current vehicle database. If a model is not available, then a vehicle of appropriate make and model may be digitized and surface model built. The digitization of the vehicle consists of point collection of the front half of the vehicle, and then a mesh generation of these points. Due to limited availability of vehicle data, basic suspension and stiffness characteristics are used. This method is similar to that discussed by Rooij et al. (2003). If neither option is available, a vehicle model of similar geometry to the case vehicle will be used.

Pedestrian Model Selection

There are five validated human pedestrian models available in MADYMO that are used for selecting an appropriate anthropometry: a 3 year-old, 6 year-old, 5th percentile female, 50th male, and 95th percentile male (Figure 1).

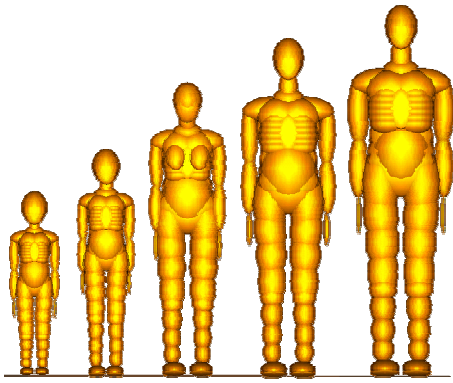


Figure 1: MADYMO Pedestrian Anthropometries

Pedestrian & Vehicle Dynamics

The pre-impact and avoidance dynamics of the pedestrian are taken into account. The vehicle, walking speed, possible orientation, and possible impact avoidance are simulated. The pre-impact and any avoidance dynamics of the driver are taken into account based on data from the police report. This includes vehicle speed, orientation, and braking.

Simulation Matrix

After a suitable vehicle model and pedestrian anthropometry have been selected, an initial simulation run is performed. The vehicle is positioned perpendicular to the pedestrian at the driver reported speed with no braking involved. Nose dive is also not accounted for in the initial run, since the majority of the cases do not indicate any driver initiated pre-impact avoidance maneuver.

The pedestrian is initially orientated with an arbitrary walking stance crossing in front of the vehicle at the noted possible vehicle contact points. This base stance is an initial guess resulting from pedestrian or witness reported observations. Using previous simulation studies from Meissner et al. (2004), this stance is further evaluated in future runs.

Once a suitable initial simulation is run, modifications to the pedestrian stance are performed to better match the lower extremity injury points to vehicle contact and/or damage points. This includes, but is not limited to, lower limb orientation (struck limb forward, struck limb back or feet together), weight bearing extremity, and knee flexion. Since lower limb injury may not be from the direct contact

with the vehicle, the contact points are used as guidelines for pedestrian stance.

After the pedestrian stance modification, if the kinematics do not sufficiently reproduce a desired result, further simulation modifications are performed. The next step is to verify vehicle dynamics, such as speed, orientation, braking, and associated brake-diver. Other simulation factors considered are upper extremity orientation, torso orientation, head and neck orientation, pedestrian speed and orientation toward vehicle, vehicle weight, etc.

Case Review

A pedestrian case review takes place approximately every three months, at which three pedestrian crashes are reviewed. To protect patient privacy, participation in the review of the cases is by invitation only and includes the treating physicians, scene responders, engineers and representatives from NHTSA and the automobile industry. A three-page case summary of each case and corresponding PowerPoint presentation are prepared.

Prior to CIREN Case Review, the principal investigator, research fellow, crash reconstructionist and study coordinator meet for an internal review to discuss the scheduled cases. Following the internal review, the crash reconstructionist and study coordinator meet with researchers from the University of Virginia – Center for Applied Biomechanics, who serve as biomechanical consultants to the CIREN Center. The case is reviewed, and kinematics are discussed extensively. After the initial reviews, the cases are then presented for a full case review, including physicians, medical students, engineers from the automobile industry, first responders, and safety researchers from NHTSA, IIHS, and University of Virginia.

Each case is presented in detail, including scene photos, vehicle photos, interior and exterior vehicle movies, pre-hospital information, hospital information, rehabilitation information, patient photos, and scans of radiographs. Relevant biomechanical information, simulation results and test data are also presented. The attending group reviews all information presented and participates in a discussion to determine pedestrian kinematics and injury mechanisms. Each injury is reviewed in detail, and review of the vehicle damage, an injury source is assigned.

RESULTS

Screening & Enrollment

Screening of pedestrian cases at the CIREN Center began in 2002. Since that time over 350 cases have been screened and over 30 pedestrian cases were enrolled for detailed investigation. Nearly half of the cases screened did not meet the minimum injury criteria level necessary for enrollment. About 50 cases were excluded due to lack of patient and vehicle owner consent and over 100 cases did not meet the requisite crash criteria or were excluded for other reasons.

The cases enrolled have encompassed a wide range of pedestrians, vehicles, and impact configurations. The pedestrians include an age range from young children to the elderly with a wide range of anthropometries. The vehicles cover a broad spectrum including numerous cars, vans, and light trucks built between 1990 and present. The impact configurations are largely of lateral pedestrian orientation, but cover a broad speed range with variations in impact point, vehicle movement, and pedestrian kinematics.

Sample Case

Included here is a sample case to illustrate the typical result of the pedestrian crash investigation, reconstruction, and Case Review.

Event Information

Striking Vehicle:	1992 Mid-size Sedan
Crash Type:	Frontal
Time of Day:	19:35
Weather:	Clear
Road Conditions:	Dry
Posted Speed:	35 mph
Police Reported Speed:	35-40 mph
Witness Reported Speed:	None

Pedestrian Data

Age:	55
Gender:	Female
Clothing:	Pants/sweater/medium length coat
Shoes:	Medium heels (< 1")
Eyewear:	None
Other object:	Purse over left shoulder
Weight:	150 lbs
Height:	168 cm
Ground to center of knee cap:	43 cm
Ground to top of hip bone:	92 cm
Ground to top of shoulder:	136 cm

Patient Interview

The patient only remembered that she was walking across the street when she was struck at the right side. She does not remember seeing the vehicle, and only remembers waking up when the paramedics were cutting off her coat.

Injury Severity

ISS Score	17
Maximum AIS:	3
Caused by injury:	Humerus fracture

Injury Analysis:

The case participant is a 55-year-old female who attempted to cross a four-lane roadway. The vehicle was traveling in the left through lane in a westbound direction. The pedestrian crossed the eastbound lanes and was struck on the right side upon entering the westbound left through lane (Figure 2). The weather was clear, and the roadway was dry. The posted speed is 35 mph.

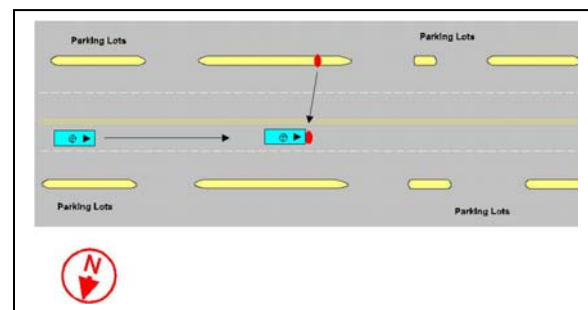


Figure2. Pedestrian Scene Diagram

Upon arrival of pre-hospital personnel, the pedestrian was alert and oriented. It was noted that there was significant depression to the hood and windshield of the vehicle. The pedestrian was noted to have multiple abrasions and was immobilized and intravenous fluids started. She was transported to the trauma center by ground.

On initial presentation in the trauma bay, the patient was amnesic to the event and complaining of pain to her head, shoulder and leg. She was hypertensive, with oxygen saturation on non-rebreather of 92% and had a GCS of 15. She was noted to have some abrasions, deformity of her right shoulder and edema of her right ankle. Radiological evaluation identified a right humerus fracture, right tibial plateau and fibula fractures and lateral malleolus fracture. CT of the head was negative for intracranial injury, but clinical examination was consistent with a concussion. She was admitted to the floor and taken to the operating room on hospital day # 2 for open reduction/internal fixation of the humerus fracture and application of a long leg cast.

Her hospital course was uneventful, and she was discharged home with her family on hospital day # 7. At the time of discharge, she was non-weight bearing on her right lower and right upper extremities.

Modeling of the crash suggested that the pedestrian had the right foot forward when she was struck which caused her to rotate backward as she falls onto the hood of the vehicle. Her head struck the base of the windshield causing the scalp contusion and concussion. Her arm suffered a direct blow as she struck the hood resulting in the transverse humerus fracture and possibly the abrasion to her hand. The bumper of the vehicle struck her right leg which bends around the bumper causing the tibial plateau and fibula fractures. It was estimated that the position of her foot on the road in combination with the bumper striking the extremity was the cause of the lateral malleolus fracture.

*Table 1.
Pedestrian Injury Analysis.*

Injuries (ICD)	AIS Severity	Contact Area (Bumper, hood)	Confid. Level
Scalp contusion (920)	190402.1	Base of windshield	Certain
Concussion w/o LOC (850.0)	161000.2	Base of windshield	Certain
Arm laceration (880.03)	790602.1	Unknown	Unknown
Humerus fracture (812.21)	752604.3	Hood	Probable
Hand abrasion (914.0)	790202.1	Hood	Possible
Tibial plateau fracture (823.00)	853406.2	Bumper	Certain
Fibula neck fracture (823.01)	851606.2	Bumper	Certain
Distal fibula fracture (823.21)	851606.2	Bumper	Certain
Lateral malleolus fracture (824.2)	851608.2	Positioning on road – bumper	Probable

DISCUSSION

Data Collection

Limitations of the CIREN approach

Retrospective analyses of pedestrian crash scenarios are difficult to perform because much of the critical information must be inferred from

forensic evidence. When compared to vehicle occupant cases, pedestrian crashes are particularly challenging because of the wider range of pedestrian contact areas (bumper area, hood, windshield, and road surface) and initial pedestrian stances. These factors increase the uncertainty of hypothesized kinematics and injury mechanisms.

Due to the injury inclusion criteria and the fact that IRTC is a Level I Trauma Center, the cases included in the project are skewed toward the most severe pedestrian impacts. It needs to be emphasized that the cases are not a representative sample of all pedestrian impacts, and this fact must be considered during data analysis.

Case Enrollment

One of the most basic challenges in performing in-depth investigation of pedestrian crashes is the enrollment of study participants. The overall enrollment rate for pedestrian crashes at the Honda Inova Fairfax Hospital CIREN Center is approximately 22% for eligible cases meeting the initial screening criteria.

Although some patients agree to take part in this study after the first contact, multiple visits are required in most instances. The socioeconomic situation of many pedestrians is different from motor vehicle or motorcycle crash victims. Working with patients who are homeless, have psychological issues or who have drug/alcohol dependencies is often very difficult. However, all patients or their family members face multiple concerns, which may include:

- Feelings of being overwhelmed by the event and the desire to avoid making additional decisions
- Advice of attorney or concern about legal issues
- Concern about insurance issues
- Feelings of guilt
- Repercussions related to immigration status
- Psychological status related to illness, addiction
- Family unavailable and patient incompetent to give consent

Establishing contact with the vehicle owner is another challenge in enrolling cases into the study. Since both the patient and the motor vehicle owner should agree to participate in order to obtain the necessary data, it is important that the motor vehicle owner also consents. Initially the identity of the vehicle owner is difficult to determine because the owner does not have a relationship with the hospital or the patient. Also, the patient usually has not obtained an accident report or made contact with the police. The crash reconstructionist has to establish

relationships with local police departments that are willing to participate in this study. Once the identity of the vehicle owner is established the crash reconstructionist attempts to contact the vehicle owner by visiting the residence. Several visits at different times are often required and many vehicle owners refuse to participate, due to:

- Feelings of guilt
- Fear of reliving the experience
- Concern about legal issues

It is important to note that only the medical staff has direct contact with the patient. For all other parties reviewing the case medical data is sanitized before viewing and there is no contact with the patient or access to personal information.

CONCLUSIONS

Application of the CIREN methodology to pedestrian crash research has proven to be a valuable tool for improving understanding of the complex interaction that occurs when a pedestrian collides with a vehicle. The combination of detailed medical knowledge with in-depth crash investigations and biomechanical expertise is helping to identify some of the injury producing mechanisms associated with pedestrian injuries and fatalities.

There is currently a minimal amount of pedestrian impact data on recent model vehicles that include pedestrian protection features, and a limited number of cases which we are able to collect at the Honda Inova Fairfax CIREN Center. Therefore, in the future, it is hoped that NHTSA will allow other CIREN centers that are interested in pedestrian safety to begin to collect pedestrian crash cases as a part of their CIREN case load.

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